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(54) **PALLETIZING MOBILE DRIVE UNITS**

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B66F 9/06 (2006.01)

(52) **U.S. Cl.**
CPC **B66F 9/063** (2013.01); **B65D 19/00**
(2013.01)

(58) **Field of Classification Search**
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USPC **414/286**
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,571,141 A 2/1986 Gieson et al.
8,256,615 B2 * 9/2012 Goda **B65D 19/06**
108/55.1
8,280,547 B2 10/2012 D'Andrea et al.
9,008,828 B2 * 4/2015 Worsley **G06Q 10/087**

9,075,412 B2 * 7/2015 Dixon **700/213**
2007/0140817 A1 * 6/2007 Hansl **G05D 1/0022**
414/277
2012/0143427 A1 6/2012 Hoffman et al.
2013/0190963 A1 * 7/2013 Kuss **B66F 9/063**
701/23
2013/0302132 A1 * 11/2013 D'Andrea **G06Q 10/08**
414/807
2014/0074341 A1 * 3/2014 Weiss **B66F 9/063**
701/25
2014/0228999 A1 * 8/2014 D'Andrea **B66F 9/063**
700/214
2015/0073589 A1 * 3/2015 Khodl **B25J 5/007**
700/218

FOREIGN PATENT DOCUMENTS

DE 202010010624 11/2010
DE 102009049563 4/2011
GB 2273281 6/1994

OTHER PUBLICATIONS

PCT/US2015/037012, "International Search Report and written
opinion", mailed Oct. 22, 2015, 10 pages.

* cited by examiner

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(57) **ABSTRACT**

An inventory system includes a pallet and a base for pallet-
izing or unpalletizing a mobile drive unit. The pallet has a set
of openings corresponding with features of the mobile drive
unit. The mobile drive unit features may extend into the pallet
openings. The base includes protrusions corresponding to the
pallet openings. Engaging the pallet and base can position the
base protrusions in the pallet openings. Positioning the base
protrusions in the pallet openings can displace the mobile
drive unit features from the pallet openings and/or provide a
surface upon which the mobile drive unit can navigate.

20 Claims, 11 Drawing Sheets

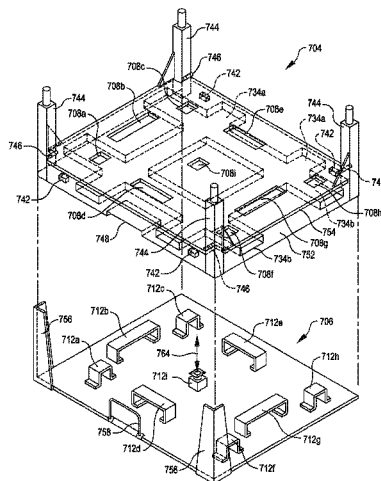


FIG. 1

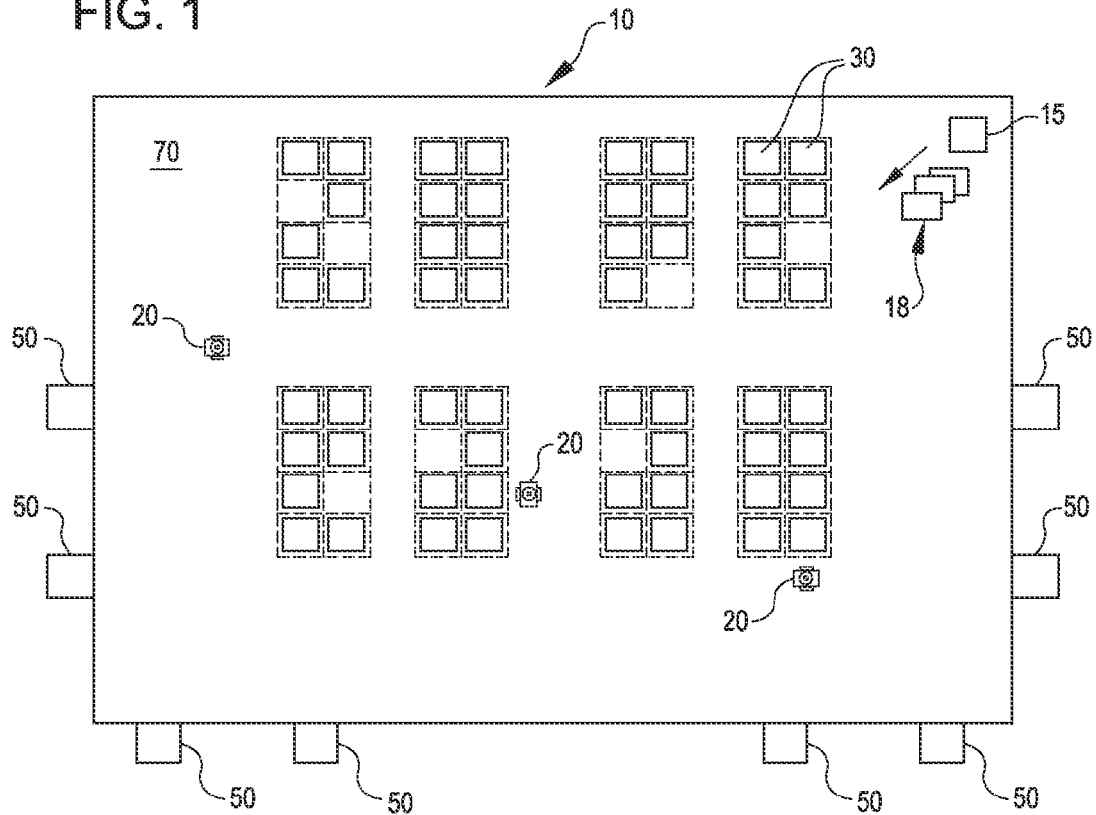


FIG. 2

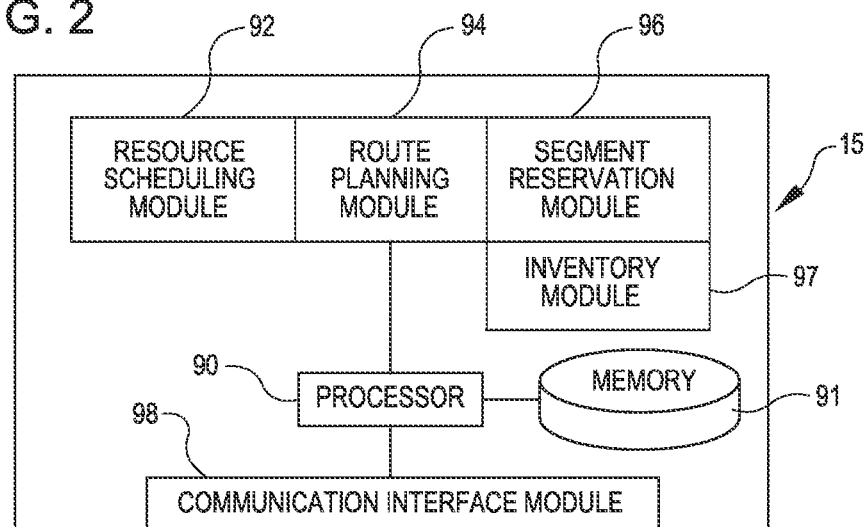


FIG. 3

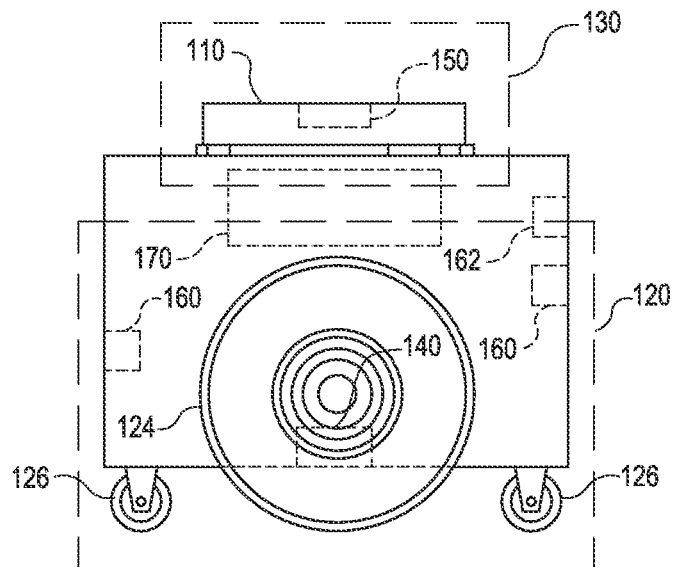


FIG. 4

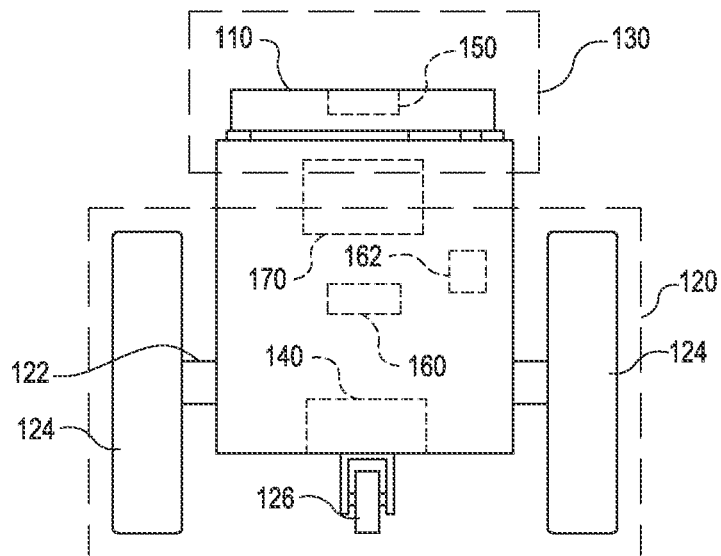


FIG. 5

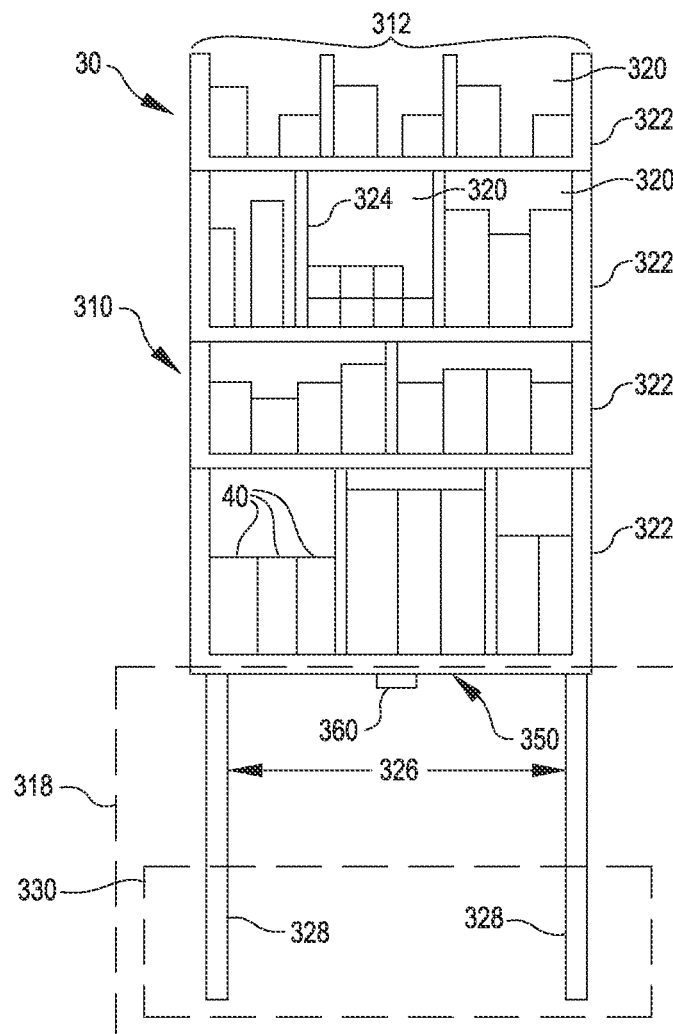


FIG. 6

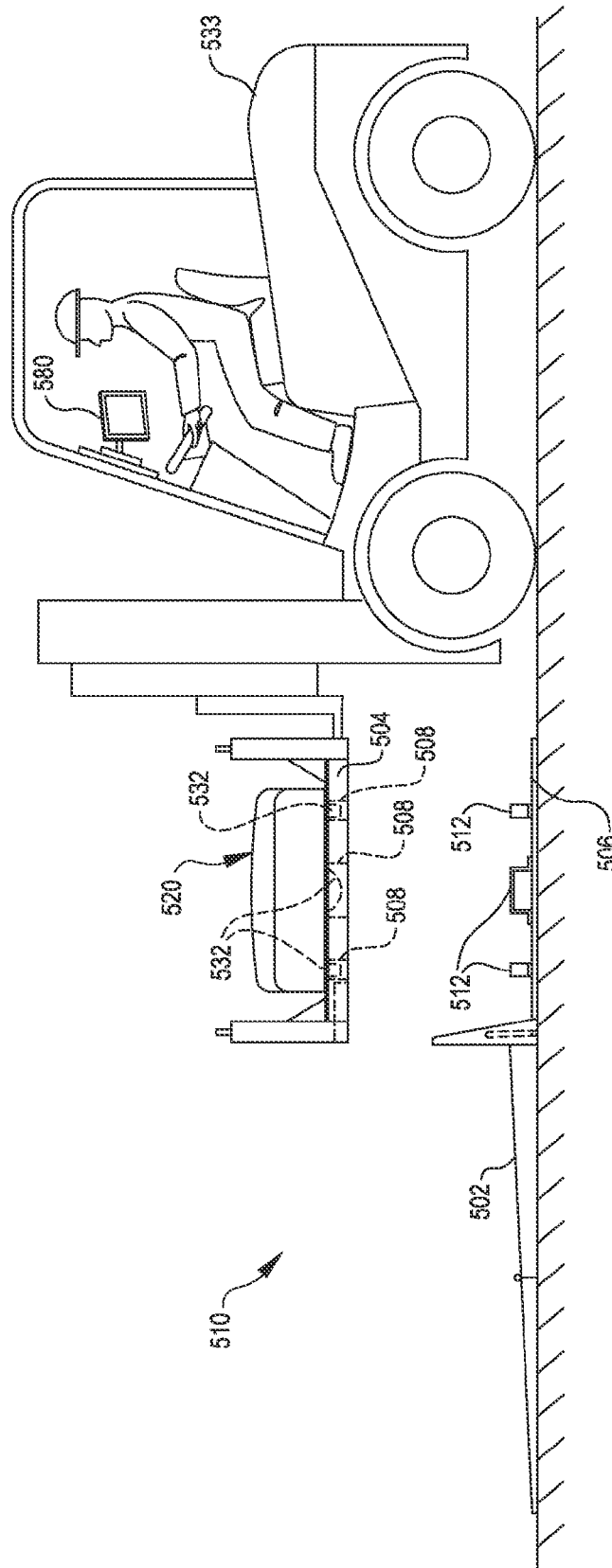
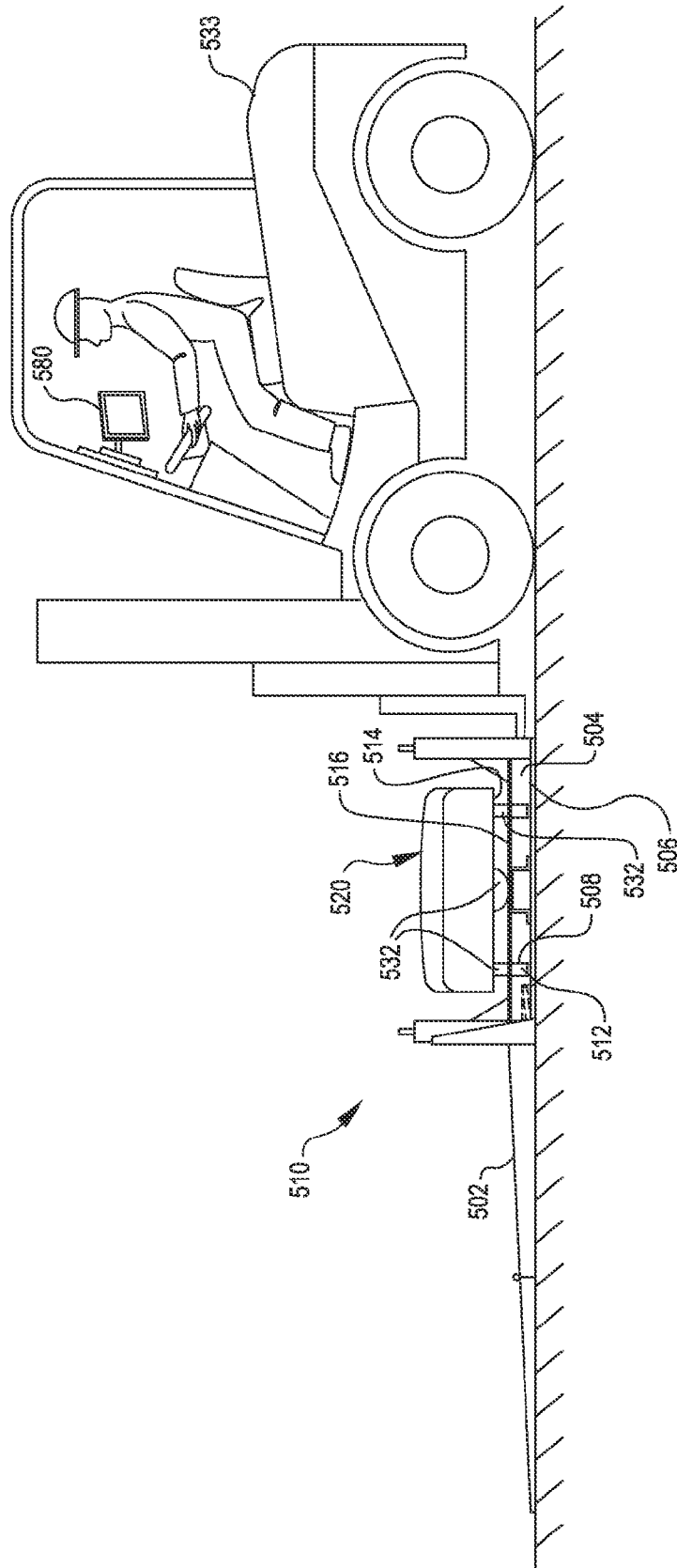


FIG. 7



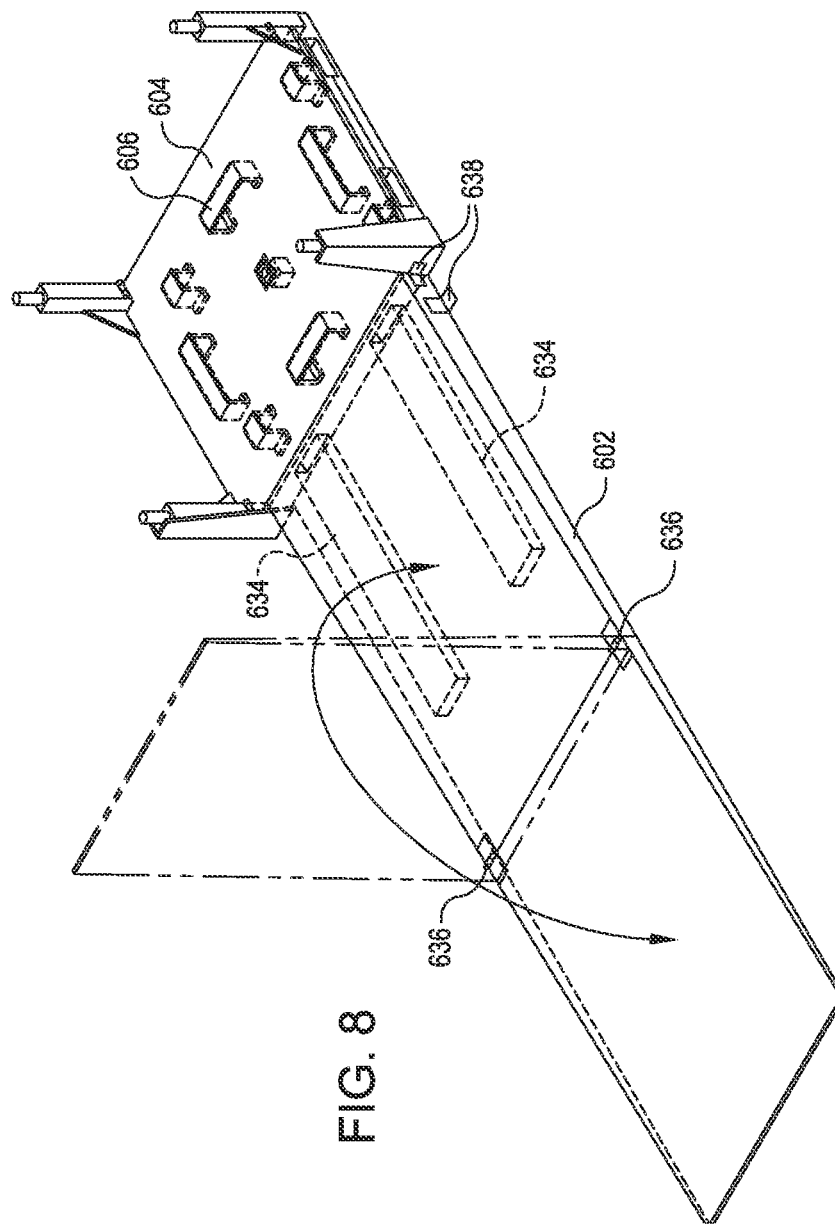


FIG. 9

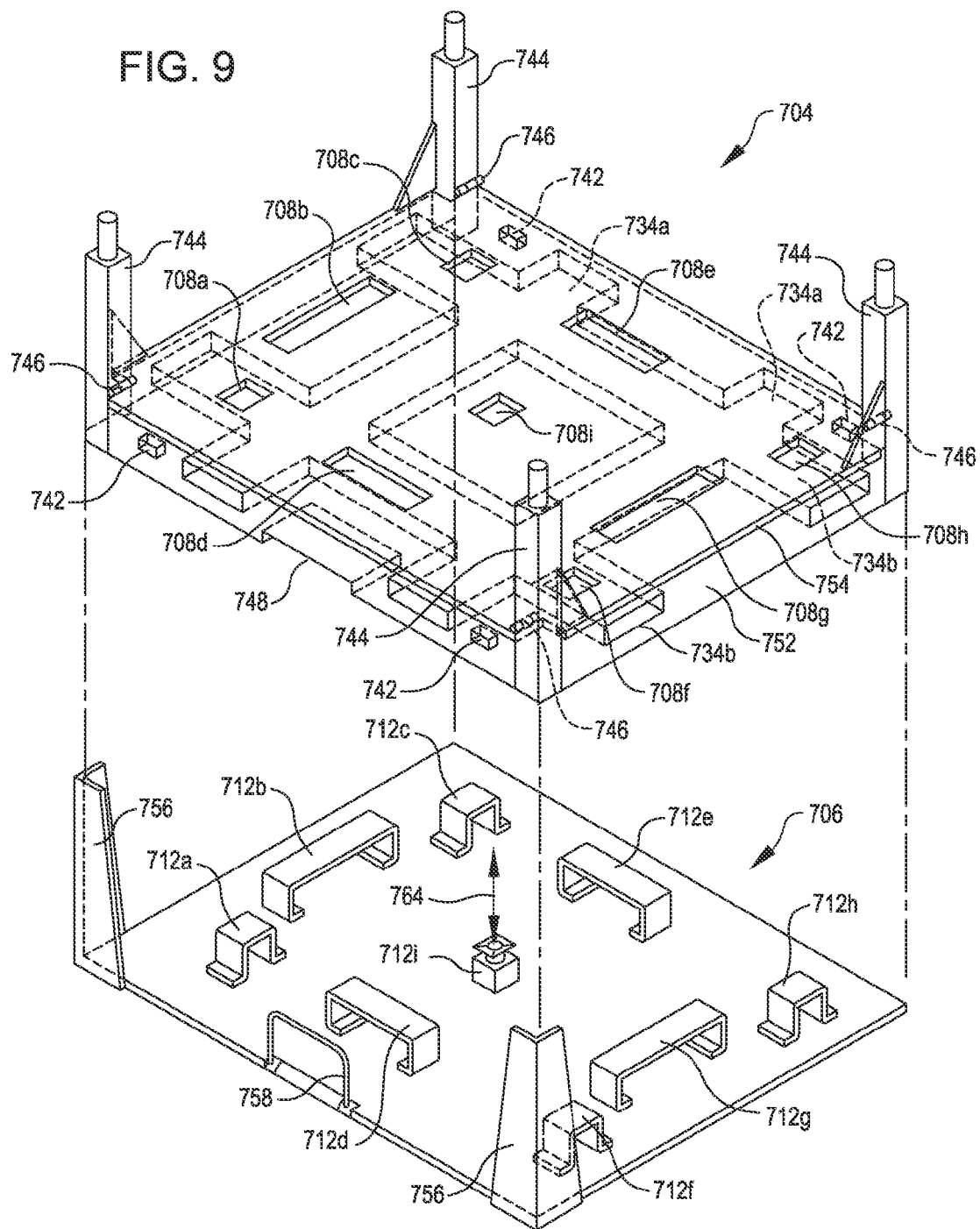


FIG. 10

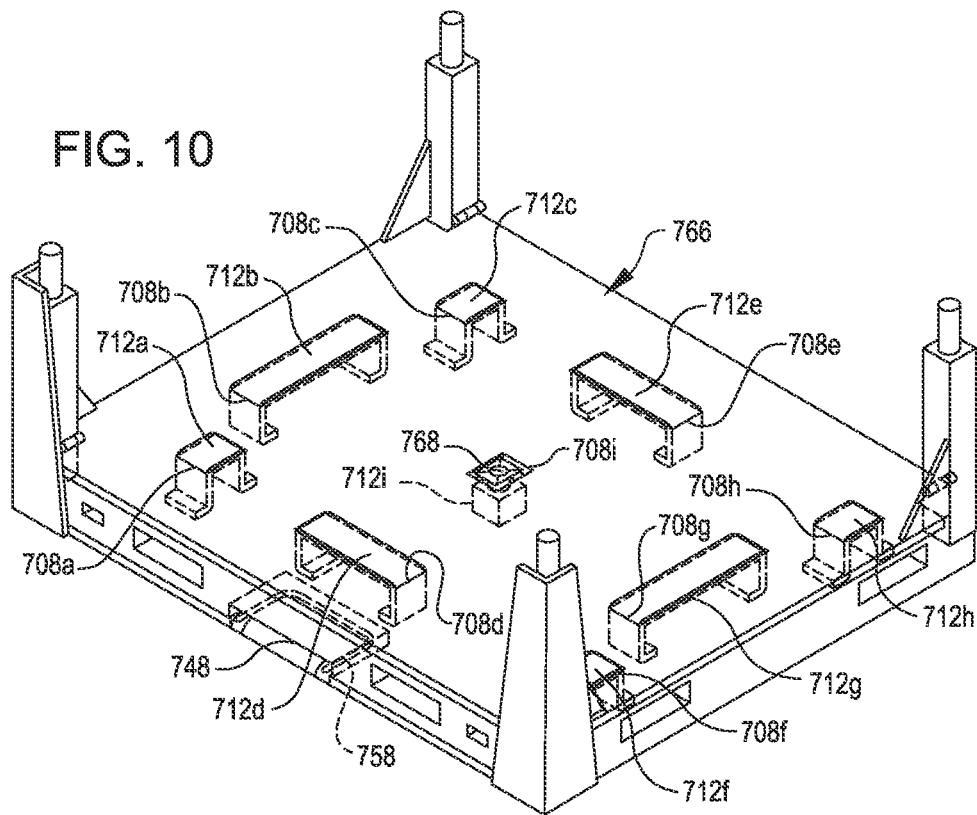


FIG. 11

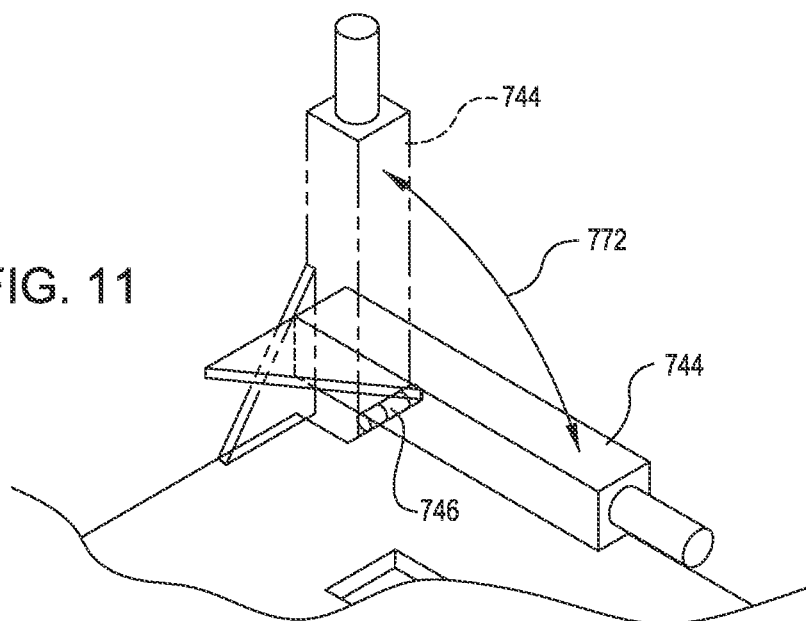


FIG. 12

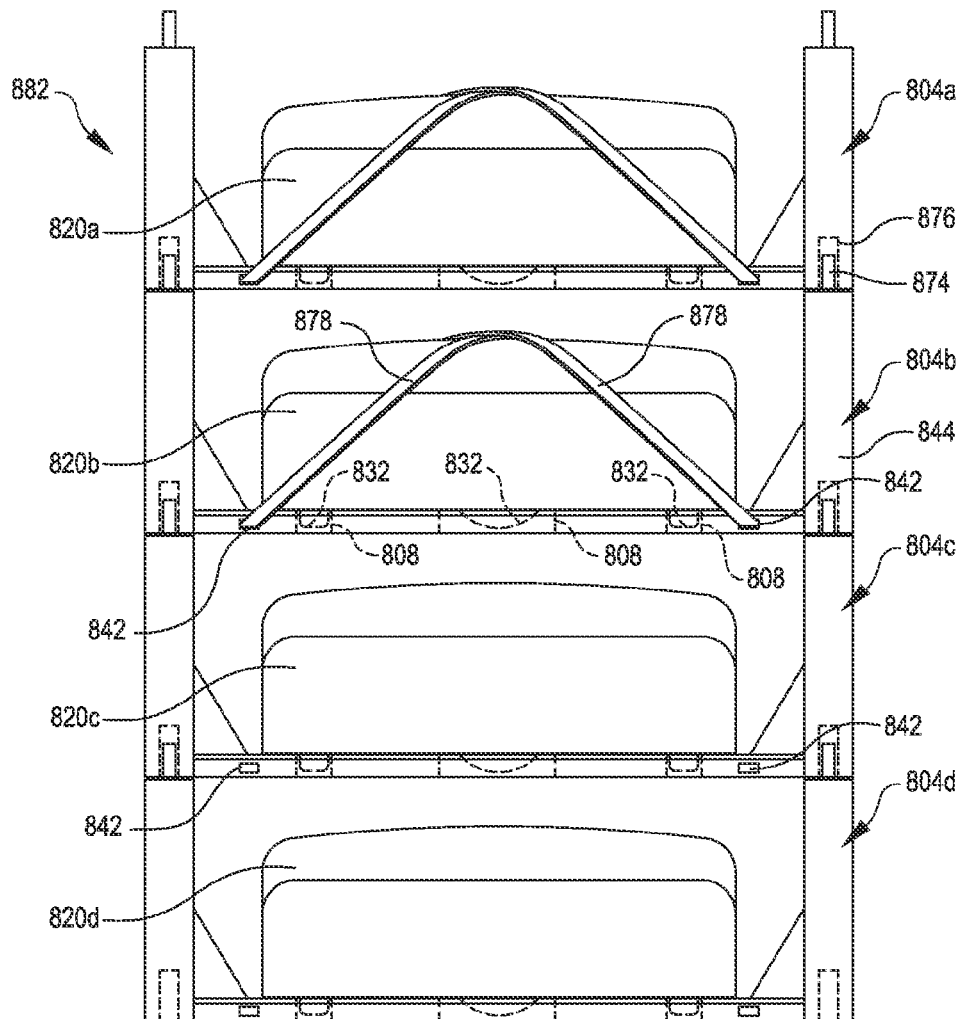


FIG. 13

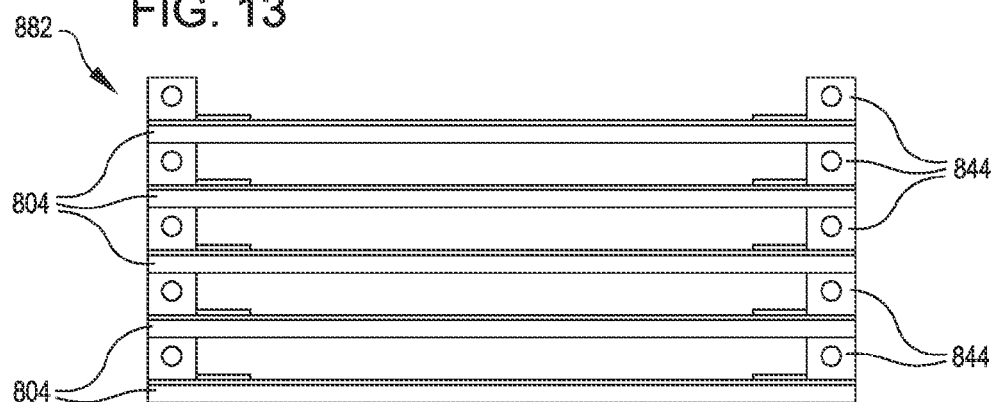


FIG. 14

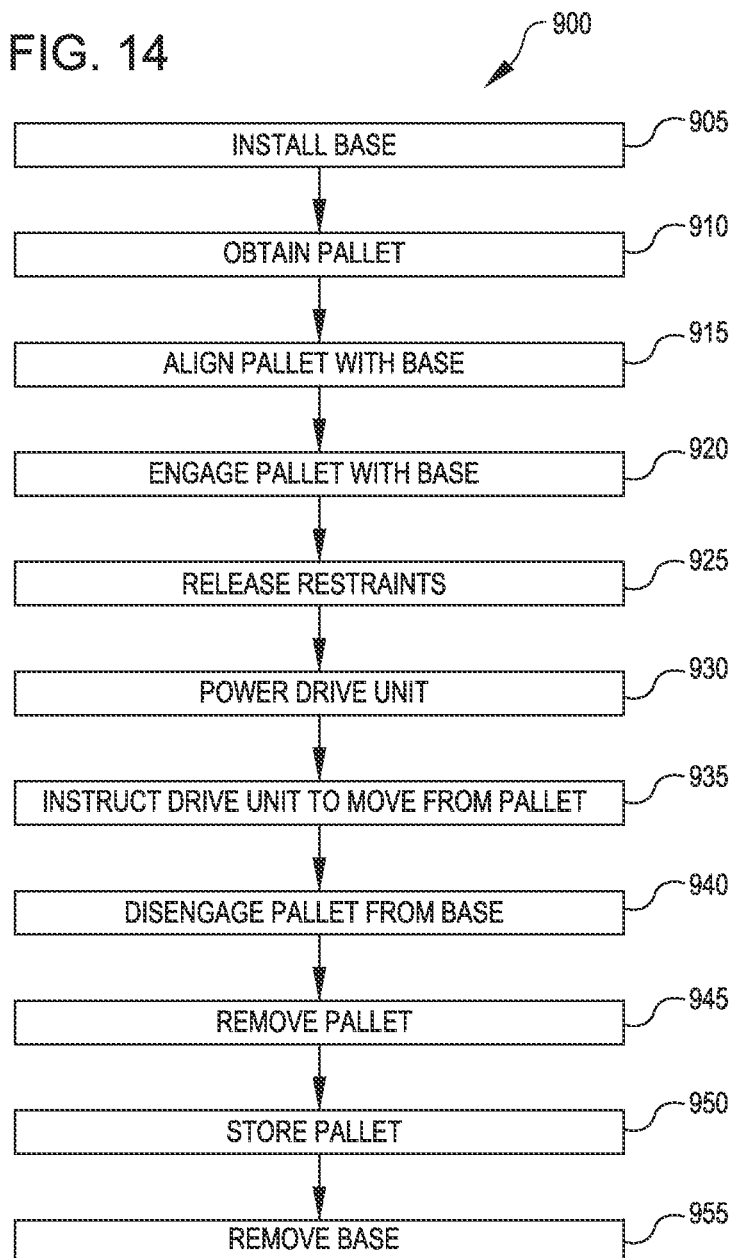
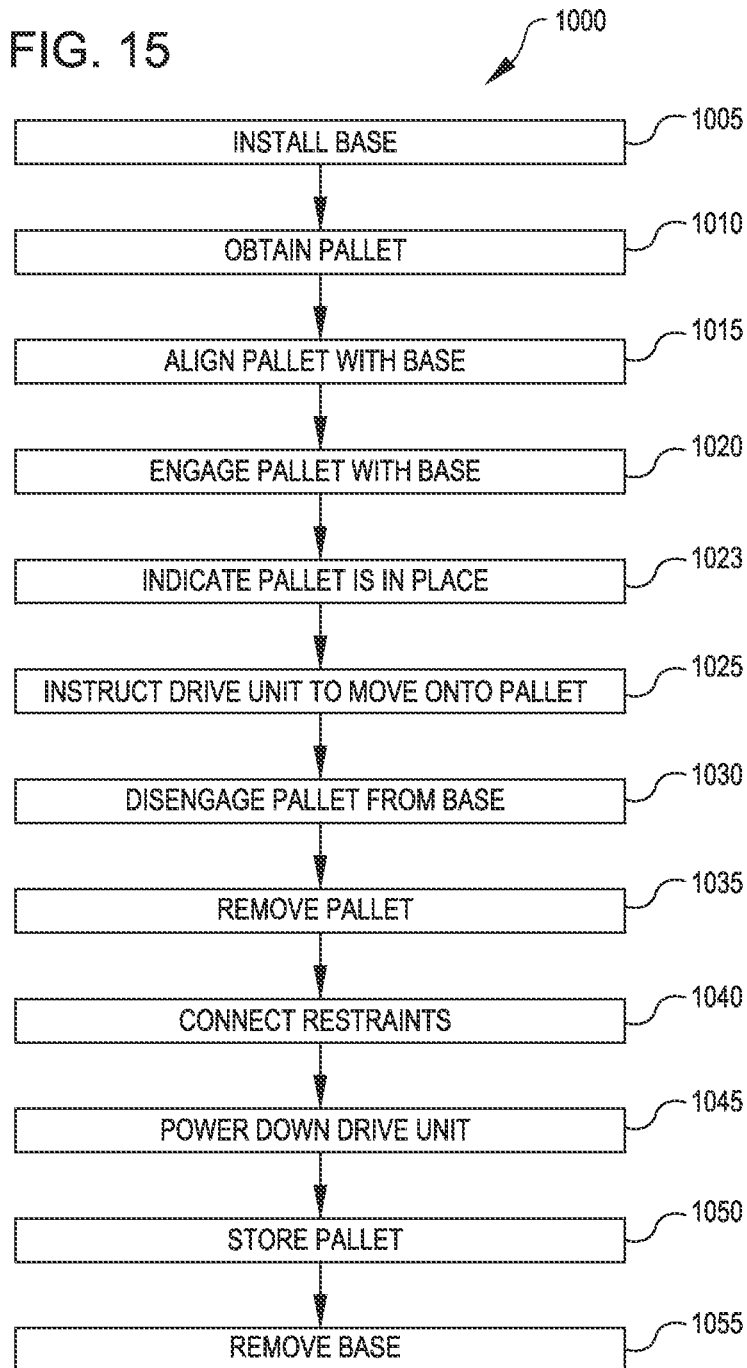


FIG. 15



PALLETIZING MOBILE DRIVE UNITS

BACKGROUND

Modern inventory systems, such as those in mail order warehouses, supply chain distribution centers, airport luggage systems, and custom-order manufacturing facilities, face significant challenges in responding to requests for inventory items. As inventory systems grow, the challenges of simultaneously completing a large number of packing, storing, and other inventory-related tasks become non-trivial. In inventory systems tasked with responding to large numbers of diverse inventory requests, inefficient utilization of system resources, including space, equipment, and manpower, can result in lower throughput, unacceptably long response times, an ever-increasing backlog of unfinished tasks, and, in general, poor system performance. Additionally, expanding or reducing the size or capabilities of many inventory systems requires significant changes to existing infrastructure and equipment. As a result, the cost of incremental changes to capacity or functionality may be prohibitively expensive, limiting the ability of the system to accommodate fluctuations in system throughput.

BRIEF DESCRIPTION OF THE DRAWINGS

Various embodiments in accordance with the present disclosure will be described with reference to the drawings, in which:

FIG. 1 illustrates components of an inventory system according to a particular embodiment;

FIG. 2 illustrates in greater detail the components of an example management module that may be utilized in particular embodiments of the inventory system shown in FIG. 1;

FIGS. 3 and 4 illustrate in greater detail an example mobile drive unit that may be utilized in particular embodiments of the inventory system shown in FIG. 1;

FIG. 5 illustrates in greater detail an example inventory holder that may be utilized in particular embodiments of the inventory system shown in FIG. 1;

FIG. 6 illustrates a pallet and corresponding base in a separate configuration according to a particular embodiment;

FIG. 7 illustrates the pallet and corresponding base of FIG. 6 in an engaged configuration according to a particular embodiment;

FIG. 8 illustrates an example of a ramp that may be utilized according to a particular embodiment;

FIG. 9 illustrates in greater detail an example pallet and base according to a particular embodiment;

FIG. 10 illustrates the base and pallet of FIG. 9 in an engaged configuration according to a particular embodiment;

FIG. 11 illustrates in greater detail an example of a post of the pallet of FIGS. 9 and 10 according to a particular embodiment;

FIG. 12 illustrates an example of stacked pallets supporting mobile drive units according to a particular embodiment;

FIG. 13 illustrates stacked pallets without mobile drive units according to a particular embodiment;

FIG. 14 is a flowchart illustrating a process of unloading mobile drive units from pallets according to a particular embodiment;

FIG. 15 illustrates a flowchart illustrating a process for loading mobile drive units onto pallets according to a particular embodiment.

DETAILED DESCRIPTION

In the following description, various embodiments will be described. For purposes of explanation, specific configura-

tions and details are set forth in order to provide a thorough understanding of the embodiments. However, it will also be apparent to one skilled in the art that the embodiments may be practiced without the specific details. Furthermore, well-known features may be omitted or simplified in order not to obscure the embodiment being described.

Embodiments herein are directed to an inventory system having multiple inventory holders and drive units for moving the inventory holders. Examples of such inventory systems are disclosed in U.S. Patent Publication No. 2012/0143427, published on Jun. 7, 2012, titled "SYSTEM AND METHOD FOR POSITIONING A MOBILE DRIVE UNIT" and U.S. Pat. No. 8,280,547, issued on Oct. 2, 2012, titled "METHOD AND SYSTEM FOR TRANSPORTING INVENTORY ITEMS", the entire disclosures of which are herein incorporated by reference. Specifically, features herein are directed to palletizing and/or unpalletizing mobile drive units, such as for loading or unloading mobile drive units with respect to shipping the mobile drive units from one location to another. To this end, the inventory system may include pallets, bases, and ramps to facilitate the palletizing process.

In accordance with an embodiment, a pallet can have a set of openings defined through the pallet. The openings can be arranged to correspond with wheels or other features that extend below a bottom surface of a mobile drive unit. During shipping, the wheels or other features may extend into the openings and allow the body of the mobile drive unit to rest on a support surface of the pallet. A base corresponding to the pallet can include a number of protrusions arranged to match the set of openings in or through the pallet. When the pallet is placed on the base, the protrusions can extend through the openings and displace the wheels or other features that were in the openings during shipment. The shape of the protrusions can match the shape of the openings such that the top of the protrusions form a combined surface with the top surface of the pallet. This combined surface may be smooth, consistent, or continuous enough to allow the mobile drive unit to drive or navigate on the combined surface without features of the mobile drive unit catching in the openings of the pallet. In one example the mobile drive unit can drive off of the pallet and down a ramp in order to join other mobile drive units in an inventory system. In another example, the same or a different mobile drive unit can drive up the ramp onto the same or a different pallet and navigate upon the combined surface of the pallet and the base protrusions. The mobile drive unit can navigate into a position in which the wheels and/or other features extending below the bottom surface of the mobile drive unit are aligned over the protrusions. The pallet can be disengaged from the base to allow the wheels and/or other features of the mobile drive unit to extend into the openings of the pallet as the protrusions are withdrawn from the openings.

Referring now to the drawings, in which features that are identified by differing reference numerals across different drawings but share common names in the description herein may refer to features that may or may not differ across embodiments, FIG. 1 illustrates the contents of an inventory system 10. Inventory system 10 includes a management module 15, one or more mobile drive units 20, one or more inventory holders 30, and one or more inventory stations 50. Mobile drive units 20 transport inventory holders 30 between points within a workspace 70 in response to commands communicated by management module 15. Each inventory holder 30 stores one or more types of inventory items. As a result, inventory system 10 is capable of moving inventory items between locations within workspace 70 to facilitate the entry,

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processing, and/or removal of inventory items from inventory system **10** and the completion of other tasks involving inventory items.

Management module **15** assigns tasks to appropriate components of inventory system **10** and coordinates operation of the various components in completing the tasks. These tasks may relate not only to the movement and processing of inventory items, but also to the management and maintenance of the components of inventory system **10**. For example, management module **15** may assign portions of workspace **70** as parking spaces for mobile drive units **20**, the scheduled recharge or replacement of mobile drive unit batteries, the storage of empty inventory holders **30**, or any other operations associated with the functionality supported by inventory system **10** and its various components. Management module **15** may select components of inventory system **10** to perform these tasks and communicate appropriate commands and/or data to the selected components to facilitate completion of these operations. Although shown in FIG. **1** as a single, discrete component, management module **15** may represent multiple components and may represent or include portions of mobile drive units **20** or other elements of inventory system **10**. As a result, any or all of the interaction between a particular mobile drive unit **20** and management module **15** that is described below may, in particular embodiments, represent peer-to-peer communication between that mobile drive unit **20** and one or more other mobile drive units **20**. The contents and operation of an example embodiment of management module **15** are discussed further below with respect to FIG. **2**.

Mobile drive units **20** move inventory holders **30** between locations within workspace **70**. Mobile drive units **20** may represent any devices or components appropriate for use in inventory system **10** based on the characteristics and configuration of inventory holders **30** and/or other elements of inventory system **10**. In a particular embodiment of inventory system **10**, mobile drive units **20** represent independent, self-powered devices configured to freely move about workspace **70**. In alternative embodiments, mobile drive units **20** represent elements of a tracked inventory system configured to move inventory holder **30** along tracks, rails, cables, crane system, or other guidance or support elements traversing workspace **70**. In such an embodiment, mobile drive units **20** may receive power and/or support through a connection to the guidance elements, such as a powered rail. Additionally, in particular embodiments of inventory system **10** mobile drive units **20** may be configured to utilize alternative conveyance equipment to move within workspace **70** and/or between separate portions of workspace **70**. The contents and operation of an example embodiment of a mobile drive unit **20** are discussed further below with respect to FIGS. **3** and **4**.

Additionally, mobile drive units **20** may be capable of communicating with management module **15** to receive information identifying selected inventory holders **30**, transmit the locations of mobile drive units **20**, or exchange any other suitable information to be used by management module **15** or mobile drive units **20** during operation. Mobile drive units **20** may communicate with management module **15** wirelessly, using wired connections between mobile drive units **20** and management module **15**, and/or in any other appropriate manner. As one example, particular embodiments of mobile drive unit **20** may communicate with management module **15** and/or with one another using 802.11, Bluetooth, or Infrared Data Association (IrDA) standards, or any other appropriate wireless communication protocol. As another example, in a tracked inventory system **10**, tracks or other guidance elements upon which mobile drive units **20** move may be wired to facilitate communication between mobile

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drive units **20** and other components of inventory system **10**. Furthermore, as noted above, management module **15** may include components of individual mobile drive units **20**. Thus, for the purposes of this description and the claims that follow, communication between management module **15** and a particular mobile drive unit **20** may represent communication between components of a particular mobile drive unit **20**. In general, mobile drive units **20** may be powered, propelled, and controlled in any manner appropriate based on the configuration and characteristics of inventory system **10**.

Inventory holders **30** store inventory items. In a particular embodiment, inventory holders **30** include multiple storage bins with each storage bin capable of holding one or more types of inventory items. Inventory holders **30** are capable of being carried, rolled, and/or otherwise moved by mobile drive units **20**. In particular embodiments, inventory holder **30** may provide additional propulsion to supplement that provided by mobile drive unit **20** when moving inventory holder **30**.

Additionally, in particular embodiments, inventory items **40** may also hang from hooks or bars (not shown) within or on inventory holder **30**. In general, inventory holder **30** may store inventory items **40** in any appropriate manner within inventory holder **30** and/or on the external surface of inventory holder **30**.

Additionally, each inventory holder **30** may include a plurality of faces, and each bin may be accessible through one or more faces of the inventory holder **30**. For example, in a particular embodiment, inventory holder **30** includes four faces. In such an embodiment, bins located at a corner of two faces may be accessible through either of those two faces, while each of the other bins is accessible through an opening in one of the four faces. Mobile drive unit **20** may be configured to rotate inventory holder **30** at appropriate times to present a particular face and the bins associated with that face to an operator or other components of inventory system **10**.

Inventory items represent any objects suitable for storage, retrieval, and/or processing in an automated inventory system **10**. For the purposes of this description, "inventory items" may represent any one or more objects of a particular type that are stored in inventory system **10**. Thus, a particular inventory holder **30** is currently "storing" a particular inventory item if the inventory holder **30** currently holds one or more units of that type. As one example, inventory system **10** may represent a mail order warehouse facility, and inventory items may represent merchandise stored in the warehouse facility. During operation, mobile drive units **20** may retrieve inventory holders **30** containing one or more inventory items requested in an order to be packed for delivery to a customer or inventory holders **30** carrying pallets containing aggregated collections of inventory items for shipment. Moreover, in particular embodiments of inventory system **10**, boxes containing completed orders may themselves represent inventory items.

In particular embodiments, inventory system **10** may also include one or more inventory stations **50**. Inventory stations **50** represent locations designated for the completion of particular tasks involving inventory items. Such tasks may include the removal of inventory items from inventory holders **30**, the introduction of inventory items into inventory holders **30**, the counting of inventory items in inventory holders **30**, the decomposition of inventory items (e.g. from pallet- or case-sized groups to individual inventory items), the consolidation of inventory items between inventory holders **30**, and/or the processing or handling of inventory items in any other suitable manner. In particular embodiments, inventory stations **50** may just represent the physical locations where a particular task involving inventory items can be completed within workspace **70**. In alternative embodiments, inventory

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stations **50** may represent both the physical location and also any appropriate equipment for processing or handling inventory items, such as scanners for monitoring the flow of inventory items in and out of inventory system **10**, communication interfaces for communicating with management module **15**, and/or any other suitable components. Inventory stations **50** may be controlled, entirely or in part, by human operators or may be fully automated. Moreover, the human or automated operators of inventory stations **50** may be capable of performing certain tasks to inventory items, such as packing, counting, or transferring inventory items, as part of the operation of inventory system **10**.

Workspace **70** represents an area associated with inventory system **10** in which mobile drive units **20** can move and/or inventory holders **30** can be stored. For example, workspace **70** may represent all or part of the floor of a mail-order warehouse in which inventory system **10** operates. Although FIG. **1** shows, for the purposes of illustration, an embodiment of inventory system **10** in which workspace **70** includes a fixed, predetermined, and finite physical space, particular embodiments of inventory system **10** may include mobile drive units **20** and inventory holders **30** that are configured to operate within a workspace **70** that is of variable dimensions and/or an arbitrary geometry. While FIG. **1** illustrates a particular embodiment of inventory system **10** in which workspace **70** is entirely enclosed in a building, alternative embodiments may utilize workspaces **70** in which some or all of the workspace **70** is located outdoors, within a vehicle (such as a cargo ship), or otherwise unconstrained by any fixed structure.

In operation, management module **15** selects appropriate components to complete particular tasks and transmits task assignments **18** to the selected components to trigger completion of the relevant tasks. Each task assignment **18** defines one or more tasks to be completed by a particular component. These tasks may relate to the retrieval, storage, replenishment, and counting of inventory items and/or the management of mobile drive units **20**, inventory holders **30**, inventory stations **50** and other components of inventory system **10**. Depending on the component and the task to be completed, a particular task assignment **18** may identify locations, components, and/or actions associated with the corresponding task and/or any other appropriate information to be used by the relevant component in completing the assigned task.

In particular embodiments, management module **15** generates task assignments **18** based, in part, on inventory requests that management module **15** receives from other components of inventory system **10** and/or from external components in communication with management module **15**. These inventory requests identify particular operations to be completed involving inventory items stored or to be stored within inventory system **10** and may represent communication of any suitable form. For example, in particular embodiments, an inventory request may represent a shipping order specifying particular inventory items that have been purchased by a customer and that are to be retrieved from inventory system **10** for shipment to the customer. Management module **15** may also generate task assignments **18** independently of such inventory requests, as part of the overall management and maintenance of inventory system **10**. For example, management module **15** may generate task assignments **18** in response to the occurrence of a particular event (e.g., in response to a mobile drive unit **20** requesting a space to park), according to a predetermined schedule (e.g., as part of a daily start-up routine), or at any appropriate time based on the configuration and characteristics of inventory system **10**. After generating one or more task assignments **18**, manage-

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ment module **15** transmits the generated task assignments **18** to appropriate components for completion of the corresponding task. The relevant components then execute their assigned tasks.

With respect to mobile drive units **20** specifically, management module **15** may, in particular embodiments, communicate task assignments **18** to selected mobile drive units **20** that identify one or more destinations for the selected mobile drive units **20**. Management module **15** may select a mobile drive unit **20** to assign the relevant task based on the location or state of the selected mobile drive unit **20**, an indication that the selected mobile drive unit **20** has completed a previously-assigned task, a predetermined schedule, and/or any other suitable consideration. These destinations may be associated with an inventory request the management module **15** is executing or a management objective the management module **15** is attempting to fulfill. For example, the task assignment may define the location of an inventory holder **30** to be retrieved, an inventory station **50** to be visited, a storage location where the mobile drive unit **20** should park until receiving another task, or a location associated with any other task appropriate based on the configuration, characteristics, and/or state of inventory system **10**, as a whole, or individual components of inventory system **10**. For example, in particular embodiments, such decisions may be based on the popularity of particular inventory items, the staffing of a particular inventory station **50**, the tasks currently assigned to a particular mobile drive unit **20**, and/or any other appropriate considerations.

As part of completing these tasks mobile drive units **20** may dock with and transport inventory holders **30** within workspace **70**. Mobile drive units **20** may dock with inventory holders **30** by connecting to, lifting, and/or otherwise interacting with inventory holders **30** in any other suitable manner so that, when docked, mobile drive units **20** are coupled to and/or support inventory holders **30** and can move inventory holders **30** within workspace **70**. While the description below focuses on particular embodiments of mobile drive unit **20** and inventory holder **30** that are configured to dock in a particular manner, alternative embodiments of mobile drive unit **20** and inventory holder **30** may be configured to dock in any manner suitable to allow mobile drive unit **20** to move inventory holder **30** within workspace **70**. Additionally, as noted below, in particular embodiments, mobile drive units **20** represent all or portions of inventory holders **30**. In such embodiments, mobile drive units **20** may not dock with inventory holders **30** before transporting inventory holders **30** and/or mobile drive units **20** may each remain continually docked with a particular inventory holder **30**.

While the appropriate components of inventory system **10** complete assigned tasks, management module **15** may interact with the relevant components to ensure the efficient use of space, equipment, manpower, and other resources available to inventory system **10**. As one specific example of such interaction, management module **15** is responsible, in particular embodiments, for planning the paths mobile drive units **20** take when moving within workspace **70** and for allocating use of a particular portion of workspace **70** to a particular mobile drive unit **20** for purposes of completing an assigned task. In such embodiments, mobile drive units **20** may, in response to being assigned a task, request a path to a particular destination associated with the task. Moreover, while the description below focuses on one or more embodiments in which mobile drive unit **20** requests paths from management module **15**, mobile drive unit **20** may, in alternative embodiments, generate its own paths.

Components of inventory system **10** may provide information to management module **15** regarding their current state, other components of inventory system **10** with which they are interacting, and/or other conditions relevant to the operation of inventory system **10**. This may allow management module **15** to utilize feedback from the relevant components to update algorithm parameters, adjust policies, or otherwise modify its decision-making to respond to changes in operating conditions or the occurrence of particular events.

In addition, while management module **15** may be configured to manage various aspects of the operation of the components of inventory system **10**, in particular embodiments, the components themselves may also be responsible for decision-making relating to certain aspects of their operation, thereby reducing the processing load on management module **15**.

Thus, based on its knowledge of the location, current state, and/or other characteristics of the various components of inventory system **10** and an awareness of all the tasks currently being completed, management module **15** can generate tasks, allot usage of system resources, and otherwise direct the completion of tasks by the individual components in a manner that optimizes operation from a system-wide perspective. Moreover, by relying on a combination of both centralized, system-wide management and localized, component-specific decision-making, particular embodiments of inventory system **10** may be able to support a number of techniques for efficiently executing various aspects of the operation of inventory system **10**. As a result, particular embodiments of management module **15** may, by implementing one or more management techniques described below, enhance the efficiency of inventory system **10** and/or provide other operational benefits.

FIG. 2 illustrates in greater detail the components of a particular embodiment of management module **15**. As shown, the example embodiment includes a resource scheduling module **92**, a route planning module **94**, a segment reservation module **96**, an inventory module **97**, a communication interface module **98**, a processor **90**, and a memory **91**. Management module **15** may represent a single component, multiple components located at a central location within inventory system **10**, or multiple components distributed throughout inventory system **10**. For example, management module **15** may represent components of one or more mobile drive units **20** that are capable of communicating information between the mobile drive units **20** and coordinating the movement of mobile drive units **20** within workspace **70**. In general, management module **15** may include any appropriate combination of hardware and/or software suitable to provide the described functionality.

Processor **90** is operable to execute instructions associated with the functionality provided by management module **15**. Processor **90** may comprise one or more general purpose computers, dedicated microprocessors, or other processing devices capable of communicating electronic information. Examples of processor **90** include one or more application-specific integrated circuits (ASICs), field programmable gate arrays (FPGAs), digital signal processors (DSPs) and any other suitable specific or general purpose processors.

Memory **91** stores processor instructions, inventory requests, reservation information, state information for the various components of inventory system **10** and/or any other appropriate values, parameters, or information utilized by management module **15** during operation. Memory **91** may represent any collection and arrangement of volatile or non-volatile, local or remote devices suitable for storing data. Examples of memory **91** include, but are not limited to, ran-

dom access memory (RAM) devices, read only memory (ROM) devices, magnetic storage devices, optical storage devices or any other suitable data storage devices.

Resource scheduling module **92** processes received inventory requests and generates one or more assigned tasks to be completed by the components of inventory system **10**. Resource scheduling module **92** may also select one or more appropriate components for completing the assigned tasks and, using communication interface module **98**, communicate the assigned tasks to the relevant components. Additionally, resource scheduling module **92** may also be responsible for generating assigned tasks associated with various management operations, such as prompting mobile drive units **20** to recharge batteries or have batteries replaced, instructing inactive mobile drive units **20** to park in a location outside the anticipated traffic flow or a location near the anticipated site of future tasks, and/or directing mobile drive units **20** selected for repair or maintenance to move towards a designated maintenance station.

Route planning module **94** receives route requests from mobile drive units **20**. These route requests identify one or more destinations associated with a task the requesting mobile drive unit **20** is executing. In response to receiving a route request, route planning module **94** generates a path to one or more destinations identified in the route request. Route planning module **94** may implement any appropriate algorithms utilizing any appropriate parameters, factors, and/or considerations to determine the appropriate path. After generating an appropriate path, route planning module **94** transmits a route response identifying the generated path to the requesting mobile drive unit **20** using communication interface module **98**.

Segment reservation module **96** receives reservation requests from mobile drive units **20** attempting to move along paths generated by route planning module **94**. These reservation requests request the use of a particular portion of workspace **70** (referred to herein as a "segment") to allow the requesting mobile drive unit **20** to avoid collisions with other mobile drive units **20** while moving across the reserved segment. In response to received reservation requests, segment reservation module **96** transmits a reservation response granting or denying the reservation request to the requesting mobile drive unit **20** using the communication interface module **98**.

The inventory module **97** maintains information about the location and number of inventory items **40** in the inventory system **10**. Information can be maintained about the number of inventory items **40** in a particular inventory holder **30**, and the maintained information can include the location of those inventory items **40** in the inventory holder **30**. The inventory module **97** can also communicate with the mobile drive units **20**, utilizing task assignments **18** to maintain, replenish or move inventory items **40** within the inventory system **10**.

Communication interface module **98** facilitates communication between management module **15** and other components of inventory system **10**, including reservation responses, reservation requests, route requests, route responses, and task assignments. These reservation responses, reservation requests, route requests, route responses, and task assignments may represent communication of any form appropriate based on the capabilities of management module **15** and may include any suitable information. Depending on the configuration of management module **15**, communication interface module **98** may be responsible for facilitating either or both of wired and wireless communication between management module **15** and the various components of inventory system **10**. In particular

embodiments, management module 15 may communicate using communication protocols such as 802.11, Bluetooth, or Infrared Data Association (IrDA) standards. Furthermore, management module 15 may, in particular embodiments, represent a portion of mobile drive unit 20 or other components of inventory system 10. In such embodiments, communication interface module 98 may facilitate communication between management module 15 and other parts of the same system component.

In general, resource scheduling module 92, route planning module 94, segment reservation module 96, inventory module 97, and communication interface module 98 may each represent any appropriate hardware and/or software suitable to provide the described functionality. In addition, as noted above, management module 15 may, in particular embodiments, represent multiple different discrete components and any or all of resource scheduling module 92, route planning module 94, segment reservation module 96, inventory module 97, and communication interface module 98 may represent components physically separate from the remaining elements of management module 15. Moreover, any two or more of resource scheduling module 92, route planning module 94, segment reservation module 96, inventory module 97, and communication interface module 98 may share common components. For example, in particular embodiments, resource scheduling module 92, route planning module 94, segment reservation module 96, and inventory module 97 represent computer processes executing on processor 90 and communication interface module 98 comprises a wireless transmitter, a wireless receiver, and a related computer process executing on processor 90.

FIGS. 3 and 4 illustrate in greater detail the components of a particular embodiment of mobile drive unit 20. In particular, FIGS. 3 and 4 include a front and side view of an example mobile drive unit 20. Mobile drive unit 20 includes a docking head 110, a drive module 120, a docking actuator 130, and a control module 170. Additionally, mobile drive unit 20 may include one or more sensors configured to detect or determine the location of mobile drive unit 20, inventory holder 30, and/or other appropriate elements of inventory system 10. In the illustrated embodiment, mobile drive unit 20 includes a position sensor 140, a holder sensor 150, an obstacle sensor 160, and an identification signal transmitter 162.

Docking head 110, in particular embodiments of mobile drive unit 20, couples mobile drive unit 20 to inventory holder 30 and/or supports inventory holder 30 when mobile drive unit 20 is docked to inventory holder 30. Docking head 110 may additionally allow mobile drive unit 20 to maneuver inventory holder 30, such as by lifting inventory holder 30, propelling inventory holder 30, rotating inventory holder 30, and/or moving inventory holder 30 in any other appropriate manner. Docking head 110 may also include any appropriate combination of components, such as ribs, spikes, and/or corrugations, to facilitate such manipulation of inventory holder 30. For example, in particular embodiments, docking head 110 may include a high-friction portion that abuts a portion of inventory holder 30 while mobile drive unit 20 is docked to inventory holder 30. In such embodiments, frictional forces created between the high-friction portion of docking head 110 and a surface of inventory holder 30 may induce translational and rotational movement in inventory holder 30 when docking head 110 moves and rotates, respectively. As a result, mobile drive unit 20 may be able to manipulate inventory holder 30 by moving or rotating docking head 110, either independently or as a part of the movement of mobile drive unit 20 as a whole.

Drive module 120 propels mobile drive unit 20 and, when mobile drive unit 20 and inventory holder 30 are docked, inventory holder 30. Drive module 120 may represent any appropriate collection of components operable to propel drive module 120. For example, in the illustrated embodiment, drive module 120 includes motorized axle 122, a pair of motorized wheels 124, and a pair of stabilizing wheels 126. One motorized wheel 124 is located at each end of motorized axle 122, and one stabilizing wheel 126 is positioned at each end of mobile drive unit 20.

Docking actuator 130 moves docking head 110 towards inventory holder 30 to facilitate docking of mobile drive unit 20 and inventory holder 30. Docking actuator 130 may also be capable of adjusting the position or orientation of docking head 110 in other suitable manners to facilitate docking. Docking actuator 130 may include any appropriate components, based on the configuration of mobile drive unit 20 and inventory holder 30, for moving docking head 110 or otherwise adjusting the position or orientation of docking head 110. For example, in the illustrated embodiment, docking actuator 130 includes a motorized shaft (not shown) attached to the center of docking head 110. The motorized shaft is operable to lift docking head 110 as appropriate for docking with inventory holder 30.

Drive module 120 may be configured to propel mobile drive unit 20 in any appropriate manner. For example, in the illustrated embodiment, motorized wheels 124 are operable to rotate in a first direction to propel mobile drive unit 20 in a forward direction. Motorized wheels 124 are also operable to rotate in a second direction to propel mobile drive unit 20 in a backward direction. In the illustrated embodiment, drive module 120 is also configured to rotate mobile drive unit 20 by rotating motorized wheels 124 in different directions from one another or by rotating motorized wheels 124 at different speed from one another.

Position sensor 140 represents one or more sensors, detectors, or other components suitable for determining the location of mobile drive unit 20 in any appropriate manner. For example, in particular embodiments, the workspace 70 associated with inventory system 10 includes a number of fiducial marks that mark points on a two-dimensional grid that covers all or a portion of workspace 70. In such embodiments, position sensor 140 may include a camera and suitable image- and/or video-processing components, such as an appropriately-programmed digital signal processor, to allow position sensor 140 to detect fiducial marks within the camera's field of view. Control module 170 may store location information that position sensor 140 updates as position sensor 140 detects fiducial marks. As a result, position sensor 140 may utilize fiducial marks to maintain an accurate indication of the location mobile drive unit 20 and to aid in navigation when moving within workspace 70.

Holder sensor 150 represents one or more sensors, detectors, or other components suitable for detecting inventory holder 30 and/or determining, in any appropriate manner, the location of inventory holder 30, as an absolute location or as a position relative to mobile drive unit 20. Holder sensor 150 may be capable of detecting the location of a particular portion of inventory holder 30 or inventory holder 30 as a whole. Mobile drive unit 20 may then use the detected information for docking with or otherwise interacting with inventory holder 30.

Obstacle sensor 160 represents one or more sensors capable of detecting objects located in one or more different directions in which mobile drive unit 20 is capable of moving. Obstacle sensor 160 may utilize any appropriate components and techniques, including optical, radar, sonar, pressure-sens-

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ing and/or other types of detection devices appropriate to detect objects located in the direction of travel of mobile drive unit 20. In particular embodiments, obstacle sensor 160 may transmit information describing objects it detects to control module 170 to be used by control module 170 to identify obstacles and to take appropriate remedial actions to prevent mobile drive unit 20 from colliding with obstacles and/or other objects.

Obstacle sensor 160 may also detect signals transmitted by other mobile drive units 20 operating in the vicinity of the illustrated mobile drive unit 20. For example, in particular embodiments of inventory system 10, one or more mobile drive units 20 may include an identification signal transmitter 162 that transmits a drive identification signal. The drive identification signal indicates to other mobile drive units 20 that the object transmitting the drive identification signal is in fact a mobile drive unit. Identification signal transmitter 162 may be capable of transmitting infrared, ultraviolet, audio, visible light, radio, and/or other suitable signals that indicate to recipients that the transmitting device is a mobile drive unit 20.

Additionally, in particular embodiments, obstacle sensor 160 may also be capable of detecting state information transmitted by other mobile drive units 20. For example, in particular embodiments, identification signal transmitter 162 may be capable of including state information relating to mobile drive unit 20 in the transmitted identification signal. This state information may include, but is not limited to, the position, velocity, direction, and the braking capabilities of the transmitting mobile drive unit 20. In particular embodiments, mobile drive unit 20 may use the state information transmitted by other mobile drive units to avoid collisions when operating in close proximity with those other mobile drive units.

Control module 170 monitors and/or controls operation of drive module 120 and docking actuator 130. Control module 170 may also receive information from sensors such as position sensor 140 and holder sensor 150 and adjust the operation of drive module 120, docking actuator 130, and/or other components of mobile drive unit 20 based on this information. Additionally, in particular embodiments, mobile drive unit 20 may be configured to communicate with a management device of inventory system 10 and control module 170 may receive commands transmitted to mobile drive unit 20 and communicate information back to the management device utilizing appropriate communication components of mobile drive unit 20. Control module 170 may include any appropriate hardware and/or software suitable to provide the described functionality. In particular embodiments, control module 170 includes a general-purpose microprocessor programmed to provide the described functionality. Additionally, control module 170 may include all or portions of docking actuator 130, drive module 120, position sensor 140, and/or holder sensor 150, and/or share components with any of these elements of mobile drive unit 20.

Moreover, in particular embodiments, control module 170 may include hardware and software located in components that are physically distinct from the device that houses drive module 120, docking actuator 130, and/or the other components of mobile drive unit 20 described above. For example, in particular embodiments, each mobile drive unit 20 operating in inventory system 10 may be associated with a software process (referred to here as a “drive agent”) operating on a server that is in communication with the device that houses drive module 120, docking actuator 130, and other appropriate components of mobile drive unit 20. This drive agent may be responsible for requesting and receiving tasks, requesting

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and receiving routes, transmitting state information associated with mobile drive unit 20, and/or otherwise interacting with management module 15 and other components of inventory system 10 on behalf of the device that physically houses drive module 120, docking actuator 130, and the other appropriate components of mobile drive unit 20. As a result, for the purposes of this description and the claims that follow, the term “mobile drive unit” includes software and/or hardware, such as agent processes, that provides the described functionality on behalf of mobile drive unit 20 but that may be located in physically distinct devices from the drive module 120, docking actuator 130, and/or the other components of mobile drive unit 20 described above.

While FIGS. 3 and 4 illustrate a particular embodiment of mobile drive unit 20 containing certain components and configured to operate in a particular manner, mobile drive unit 20 may represent any appropriate component and/or collection of components configured to transport and/or facilitate the transport of inventory holders 30. As another example, mobile drive unit 20 may represent part of an overhead crane system in which one or more crane assemblies are capable of moving within a network of wires or rails to a position suitable to dock with a particular inventory holder 30. After docking with inventory holder 30, the crane assembly may then lift inventory holder 30 and move inventory to another location for purposes of completing an assigned task.

Furthermore, in particular embodiments, mobile drive unit 20 may represent all or a portion of inventory holder 30. Inventory holder 30 may include motorized wheels or any other components suitable to allow inventory holder 30 to propel itself. As one specific example, a portion of inventory holder 30 may be responsive to magnetic fields. Inventory system 10 may be able to generate one or more controlled magnetic fields capable of propelling, maneuvering and/or otherwise controlling the position of inventory holder 30 as a result of the responsive portion of inventory holder 30. In such embodiments, mobile drive unit 20 may represent the responsive portion of inventory holder 30 and/or the components of inventory system 10 responsible for generating and controlling these magnetic fields. While this description provides several specific examples, mobile drive unit 20 may, in general, represent any appropriate component and/or collection of components configured to transport and/or facilitate the transport of inventory holders 30.

FIG. 5 illustrates in greater detail the components of a particular embodiment of inventory holder 30. In particular, FIG. 5 illustrates the structure and contents of one side of an example inventory holder 30. In a particular embodiment, inventory holder 30 may comprise any number of faces with similar or different structure. As illustrated, inventory holder 30 includes a frame 310, a plurality of legs 328, and docking surface 350.

Frame 310 holds inventory items 40. Frame 310 provides storage space for storing inventory items 40 external or internal to frame 310. The storage space provided by frame 310 may be divided into a plurality of inventory bins 320, each capable of holding inventory items 40. Inventory bins 320 may include any appropriate storage elements, such as bins, compartments, or hooks.

In a particular embodiment, frame 310 is composed of a plurality of trays 322 stacked upon one another and attached to or stacked on a base 318. In such an embodiment, inventory bins 320 may be formed by a plurality of adjustable dividers 324 that may be moved to resize one or more inventory bins 320. In alternative embodiments, frame 310 may represent a single inventory bin 320 that includes a single tray 322 and no adjustable dividers 324. Additionally, in particular embodi-

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ments, frame 310 may represent a load-bearing surface mounted on mobility element 330. Inventory items 40 may be stored on such an inventory holder 30 by being placed on frame 310. In general, frame 310 may include storage internal and/or external storage space divided into any appropriate number of inventory bins 320 in any appropriate manner.

Additionally, in a particular embodiment, frame 310 may include a plurality of device openings 326 that allow mobile drive unit 20 to position docking head 110 adjacent docking surface 350. The size, shape, and placement of device openings 326 may be determined based on the size, the shape, and other characteristics of the particular embodiment of mobile drive unit 20 and/or inventory holder 30 utilized by inventory system 10. For example, in the illustrated embodiment, frame 310 includes four legs 328 that form device openings 326 and allow mobile drive unit 20 to position mobile drive unit 20 under frame 310 and adjacent to docking surface 350. The length of legs 328 may be determined based on a height of mobile drive unit 20.

Docking surface 350 comprises a portion of inventory holder 30 that couples to, abuts, and/or rests upon a portion of docking head 110, when mobile drive unit 20 is docked to inventory holder 30. Additionally, docking surface 350 supports a portion or all of the weight of inventory holder 30 while inventory holder 30 is docked with mobile drive unit 20. The composition, shape, and/or texture of docking surface 350 may be designed to facilitate maneuvering of inventory holder 30 by mobile drive unit 20. For example, as noted above, in particular embodiments, docking surface 350 may comprise a high-friction portion. When mobile drive unit 20 and inventory holder 30 are docked, frictional forces induced between docking head 110 and this high-friction portion may allow mobile drive unit 20 to maneuver inventory holder 30. Additionally, in particular embodiments, docking surface 350 may include appropriate components suitable to receive a portion of docking head 110, couple inventory holder 30 to mobile drive unit 20, and/or facilitate control of inventory holder 30 by mobile drive unit 20.

Holder identifier 360 marks a predetermined portion of inventory holder 30 and mobile drive unit 20 may use holder identifier 360 to align with inventory holder 30 during docking and/or to determine the location of inventory holder 30. More specifically, in particular embodiments, mobile drive unit 20 may be equipped with components, such as holder sensor 150, that can detect holder identifier 360 and determine its location relative to mobile drive unit 20. As a result, mobile drive unit 20 may be able to determine the location of inventory holder 30 as a whole. For example, in particular embodiments, holder identifier 360 may represent a reflective marker that is positioned at a predetermined location on inventory holder 30 and that holder sensor 150 can optically detect using an appropriately-configured camera.

Depending on the configuration and characteristics of mobile drive unit 20 and inventory system 10, mobile drive unit 20 may move inventory holder 30 using a variety of appropriate methods. In a particular embodiment, mobile drive unit 20 is capable of moving inventory holder 30 along a two-dimensional grid, combining movement along straight-line segments with ninety-degree rotations and arcing paths to transport inventory holder 30 from the first location to the second location. Additionally, while moving, mobile drive unit 20 may use fixed objects located in the workspace as reference points to assist in navigation. For example, in particular embodiments, inventory system 10 includes multiple fiducial marks 450. Mobile drive unit 20 may be configured to detect fiducial marks 450 and to determine the location of

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mobile drive unit 20 and/or measure its movement based on the detection of fiducial marks 450.

After mobile drive unit 20 arrives at the second location, mobile drive unit 20 may perform appropriate operations to facilitate access to inventory items 40 stored in inventory holder 30. For example, mobile drive unit 20 may rotate inventory holder 30 to present a particular face of inventory holder 30 to an operator of inventory system 10 or other suitable party, such as a packer selecting inventory items 40 from inventory holder 40. Mobile drive unit 20 may also undock from inventory holder 30. Alternatively, instead of undocking at the second location, mobile drive unit 20 may transport inventory holder 30 back to the first location or to a third location after any appropriate actions have been taken involving inventory items 40. For example, after a packer has removed particular inventory items 40 from inventory holder 30, mobile drive unit 20 may return inventory holder 30 to its original storage location, a new storage location, or another inventory station. Mobile drive unit 20 may then undock from inventory holder 30 at this new location.

As described above, embodiments herein are directed to palletizing and/or unpalletizing mobile drive units 20. In accordance with some embodiments the mobile drive units 20 can be given a task assignment 18 to drive onto or off of a pallet. Using the capability of the mobile drive unit 20 to move the mobile drive unit 20 onto or off of a pallet may significantly reduce an amount of ergonomically undesirable physical labor that might otherwise be performed by human workers to move the mobile drive unit onto or off of a pallet, such as for shipping. However, features described herein may also be utilized to palletize and/or unpalletize mobile drive units 20 using physical labor rather than the self-propelling capability of a mobile drive unit 20, such as in instances when operating the mobile drive unit 20 may be impractical. Systems and techniques disclosed herein for palletizing mobile drive units 20 may also decrease complexity and/or an amount of time involved in packing or unpacking mobile drive units 20 for shipping or other functions.

FIG. 6 illustrates an example of an inventory system 510 having a pallet 504 and a corresponding base 506. The pallet 504 may include one or more openings 508 defined through the pallet 504. The openings 508 may be arranged to accommodate features 532 of a mobile drive unit 520. The features 532 may include features extending from the mobile drive unit 520 such as the motorized axle 122, the motorized wheel 124 and/or the stabilizing wheel 126 as described above with respect to FIGS. 3 and 4. The features 532 may extend below a bottom surface 514 of the mobile drive unit 520. The features 532 may extend into the openings 508 when the mobile drive unit 520 is arranged to be supported by the pallet 504, such as for shipment on the pallet 504.

The base 506 may include protrusions 512. The protrusions 512 can be arranged to correspond with the arrangement of the openings 508 of the pallet 504. The base 506 can be installed to a floor of a warehouse or other location associated with the inventory system 510. A ramp 502 may be provided with the base 506. The pallet 504 can be navigated toward the base 506 by a forklift 533, or by any other suitable means for moving the pallet 504. The pallet 504 can be lowered onto the base 506 so as to engage with the base 506.

FIG. 7 illustrates the pallet 504 in an engaged configuration with the base 506. In the engaged configuration the protrusions 512 of the base 506 can engage in and/or occupy the openings 508 of the pallet 504. The placement of the protrusions 512 in the openings 508 can displace the features 532 of the mobile drive unit 520 from the openings 508 of the pallet 504. Displacing the features 532 of the mobile drive unit 520

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can cause the bottom surface **514** of the mobile drive unit **520** to separate from the support surface **516** of the pallet **504**. The ends of the protrusions **512** of the base **506** may be substantially flush with the support surface **516** of the pallet **504** when the pallet **504** and the base **506** are in the engaged configuration. The ends of the protrusions **512** and the support surface **516** may provide a combined surface navigable by the mobile drive unit **520**. For example, the mobile drive unit **520** may use the features **532**, e.g., wheels and axles, that were displaced from the openings **508** in order to drive upon the combined surface, move off of the pallet **504**, and travel down the ramp **502**.

FIG. **8** illustrates an example of a ramp **602** that may be utilized with a pallet **604** and corresponding base **606**. The ramp **602** may be constructed of any suitable material. In an embodiment, the ramp includes diamond plate steel material decking. The ramp **602** may include features to facilitate installation, removal, and/or shipment of the ramp **602**. For example, the ramp may include one or more hinges **636** so that the ramp can be folded and take up less space when being shipped. The ramp may also include fork channels **634** to facilitate movement of the ramp, such as by the forklift **533** depicted in FIG. **5**. The ramp **602** may include features to stabilize the ramp **602**. For example, the ramp **602** can attach to other structures in any suitable manner, such as to the base **606** or a floor via bolts through one or more angled joints **638**.

FIG. **9** illustrates in greater detail an example of a pallet **704** and corresponding base **706** according to a particular embodiment. The pallet **704** can include a number of openings **708** (e.g., openings **708a-708i** identified in FIG. **9**). The openings **708** can extend through the pallet **704**. For example, the openings **708** can extend from a top surface through a bottom surface of the pallet **704**. Some or all of the openings **708** can be arranged to accommodate features of a mobile drive unit, such as features **532** described with respect to FIG. **6**. In some embodiments, the pallet **704** may also include recesses **742** to accommodate belts or restraints used to secure a mobile drive unit to the pallet **704**.

The pallet **704** may include one or more sets of fork channels **734a** and **734b** to facilitate accessing or carrying the pallet from one or more directions. For example, one set of fork channels **734a** can run between a front and a back of the pallet **704**, and a second set of fork pockets **734b** can run between a left side and a right side of the pallet **704**.

The pallet **704** may include posts **744**. The posts **744** maybe be positioned so as to support another pallet over the pallet **704** (such as may be appreciated more fully by reference to FIG. **12** and the accompanying description herein). The posts **744** may include hinges **746** or other mechanisms suitable to allow the posts **746** to move from an upright supporting position to a storage position (such as may be appreciated more fully by reference to FIGS. **11** and **13** and the accompanying description herein).

The pallet **704** may include a support layer **754** attached to a frame **752**. The frame **752** may include the fork channels **734a**, **734b** and/or the posts **744**. The openings **708** may be cut in the support layer **754**, as well as at least portions of the frame **752** that may cover openings **708** in the support layer **754**. In some embodiments, the support layer **754** is configured to be removable from the frame **752**. Such an arrangement may allow a pallet **704** to be modified easily to accommodate a different style or type of mobile drive unit. For example, a removable support layer **754** may be replaced with a different support layer **754** having a different configuration of openings **708** arranged to accommodate a different mobile drive unit. The support layer **754** and the frame **752** may be formed of any suitable material, but in a particular embodi-

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ment, a wood support layer **754** attached to a metal frame **752** is utilized. Metal for the frame may provide improved durability for portions of the pallet **704** that may be subjected to impact or significant loads (such as the fork channels **734a**, **734b** and/or the posts **744**). Forming the support layer **754** from wood may yield a lighter total weight for the pallet **704**, which may in turn reduce shipping expenses. Additionally, wood may be easier to cut when forming openings **708** and may be less costly to replace than other materials, thereby further reducing costs over a lifetime of the pallet **704**.

The base **706** can include a number of protrusions **712** (e.g., protrusions **712a-712i** identified in FIG. **9**) arranged in a pattern corresponding to the arrangement of the openings **708** in the pallet **704**, or the support layer **754** of pallet **704**. The base **706** may also include one or more guides **756**. For example, the guides **756** can be positioned at a front end of the base **706** to provide a surface against which posts **744** of the pallet **704** can be aligned when installing the pallet **704** on the base **706**. Although depicted as upright in FIG. **9**, the guides **756** may alternatively be angled, for example, so as to further direct the pallet **704** into place on the base **706** as the pallet **704** is lowered. In some aspects, the guides **756** may be foldable or otherwise retractable so as to reduce a shipping size of the base. In such cases, the guides can be erected upon installing the base.

Additionally, although description herein primarily refers to engagement of the protrusions **712** with the openings **708** as occurring as a result of lowering the pallet **704** onto the base **706**, in some embodiments, some portion of the base **706** may instead or additionally be raised toward the pallet **704**. For example, one or more of the protrusions **712** may be raised into one or more openings **708** in the pallet **704**. In some embodiments, one or more protrusions **712** may include an actuator or other mechanism to raise and/or lower the protrusions **712**, as illustrated by the arrow **764** in FIG. **9**. For example, actuation of a protrusion **712** may allow the protrusion **712** to individually or selectively be raised or lowered into an opening **708** of the pallet **704**. Selective engagement of a protrusion **712** with an opening **708** in the pallet **704** can facilitate other functions. For example, actuating a protrusion **712** may allow a sensor or other tool (such as a dynamo) to be raised into an opening **708** to contact a feature (such as the motorized wheel **124**) of a mobile drive unit to facilitate testing the feature.

In some embodiments, the base **706** can also include an obstruction **758**. The obstruction may be positioned so that, when a pallet **704** is not engaged with the base **706**, the obstruction **758** will prevent a mobile drive unit from moving onto the base **706**. In some embodiments, the obstruction **758** may be sufficiently sized so that the mobile drive unit will stop upon detecting the obstruction **758** in the path. In some embodiments, the obstruction may alternatively or additionally physically prevent the mobile drive unit from moving onto the base **706** when a pallet **704** is not in place or engaged on the base **706**. In a particular embodiment, the obstruction **758** can be a spring-loaded bar that may be pushed out of the way into an indentation **748** in the pallet **704** when the pallet **704** is engaged with the base **706** (e.g., FIG. **10**). In some aspects, as may be appreciated with reference to FIGS. **6-7**, an obstruction **758** may be positioned near either end of a ramp **502**.

FIG. **10** illustrates the pallet **704** and base **706** of FIG. **9** in an engaged configuration. The pallet **704** may be lowered onto the base **706** in order to bring the pallet **704** and the base **706** into engagement. In the engaged configuration, protrusions **712a-712i** may extend into the corresponding openings **708a-708i**. The protrusions **712** can fill the openings **708** so

that the pallet **704** and top surfaces of the protrusions **712** together form a combined surface **766** that is navigable by a mobile drive unit (i.e., so that the mobile drive unit does not get stuck while driving over openings **708** in the pallet **704**).

A fiducial marker **768** can be included on a protrusion **712i** that extends through an opening **708i** when the pallet **704** is engaged with the base **706**. The fiducial marker **768** can be used for navigation by a mobile drive unit in a manner similar to what has been described previously herein. Providing a fiducial marker **768** that remains with the base **706** as opposed to moving away with each pallet **704** can reduce the number of fiducial markers **768** implemented and reduce time or complexity that might otherwise be introduced by incorporating a new fiducial marker into a floor plan with each pallet **704**.

FIG. **11** illustrates in greater detail an example of a post **744** of the pallet **704**. The post **744** may be movable between an upright supporting position (dashed lines) and a storage position (solid lines), as illustrated by arrow **772**. The post **744** may include a hinge **746** or other mechanism to facilitate this movement.

FIG. **12** illustrates a stack **882** of pallets **804a-d** containing mobile drive units **820a-d** in accordance with a particular embodiment. The stack **882** may include pallets **804a-d** arranged such that features **832** of any particular mobile drive unit **820b** extend into openings **808** of a corresponding pallet **804b**. The pallet **804b** may include posts **844** with features for supporting another pallet **804a**. For example, the posts **844** can include a male connector **874** for engaging a female connector **876** of a second pallet **804a**.

Belts or other forms of restraints **878** can be passed over the mobile drive unit **820b** so as to further secure the mobile drive unit **820b** in place relative to the pallet **804b**. In some embodiments, the restraints **878** may latch and/or otherwise engage into recesses **842** in the pallet **804b** to secure ends of the restraints **878** in place. In some aspects, the restraints may be retractable into the recesses **842** for storage when not in use to retain a mobile drive unit **820c**.

FIG. **13** illustrates a stack of pallets **804** without mobile drive units **820**. As described above with respect to FIG. **11**, posts **844** of the pallet **804** can be adjusted from an upright supporting position to a storage position. As may be appreciated by comparing FIG. **13** with FIG. **12**, arranging the posts in the storage position can allow the pallets **804** to be stacked and shipped together in a stack that takes up less room than when mobile drive units are in place on the pallets **804**.

FIG. **14** is a flowchart illustrating a process **900** for “unpalletizing” or unloading mobile drive units from pallets according to a particular embodiment. The process **900** may introduce the mobile drive units into an inventory system, such as after shipping the mobile drive units from another location or constructing and/or testing the mobile drive units on the pallets.

At **905**, a base can be installed. For example, the base **506** can be bolted to a floor of a warehouse or other location containing an inventory system **510** (e.g., FIG. **7**). A ramp may also be installed with the base. For example, the ramp **502** may also be attached to the floor and/or to the base **506** (e.g., FIG. **7**). Any suitable form of attachment may be used, including but not limited to, bolting, welding, gluing, stapling, magnetic coupling and snapping. In some embodiments, the base and/or ramp may be installed to be permanent fixtures in the inventory system. In other embodiments, the ramp and/or base are installed so as to be removable to facilitate use of the ramp and base in another area of the warehouse or another location apart from the warehouse.

At **910**, a pallet can be obtained. For example, a forklift **533** (e.g., FIG. **6**) can lift a pallet **804** from a stack **882** in which the pallet **804** was shipped (e.g., FIG. **12**). The forklift **533** can move the pallet towards the base (e.g., pallet **504** toward base **506** in FIG. **6**).

At **915**, the pallet can be aligned with the base. For example, with reference to FIG. **9**, a forklift operator may move the pallet **704** forward until posts **744** and/or a front edge of the pallet **704** encounter a portion of the guide **756**. Aligning the pallet **704** with the guide **756** can increase the likelihood that protrusions **712** of the base **706** will align correctly with the openings **708** on the pallet **704**.

At **920**, the pallet can be engaged with the base. For example, the protrusions **712** can be introduced into the openings **708** (e.g., FIG. **9-10**). In the illustrated example of FIGS. **6** and **7**, engaging the pallet **504** with the base **506** may be accomplished by lowering the pallet **504** onto the base **506**. However, in some embodiments the base **506** may be raised into the pallet **504**, or one or more of the protrusions **512** of the base **506** can be actuated to engage the openings **508**. Regardless, engaging the pallet **504** with the base **506** can push features **532** of the mobile drive unit out of the openings **508** in the pallet **504** to permit the mobile drive unit **520** to navigate upon the pallet **504**.

At **925**, restraints can be released. For example, with reference to FIG. **12**, releasing the restraints **878** can allow the mobile drive unit **820b** to vertically displace relative to the pallet **804b**. As may be appreciated with reference to FIGS. **6-7**, such vertical displacement of a mobile drive unit **520** may permit features **532** to be displaced from openings **508** in response to protrusions **512** entering the openings **508** during engagement of the pallet **504** with the base **506**. In some aspects, the restraints **878** may be released while the pallet **804b** is still in or on a stack **882** (e.g., FIG. **12**) or is on a forklift and not yet engaged with a pallet (e.g., pallet **704** of FIG. **9**). Releasing the restraints **878** at such times may improve safety and/or ergonomics of the process **900** for a human operator by reducing a number of instances that the operator is bending over to reach the restraints **878**.

At **930**, the mobile drive unit can be powered on. For example, with reference to FIG. **1**, powering on the mobile drive unit **20** may allow a management module **15** to communicate with the drive unit **20** so as to provide task assignments **18**.

At **935**, the mobile drive unit can be instructed to move from the pallet that is engaged with the base. As an illustrative example, the management module **15** (e.g., FIG. **1**) may provide a task assignment **18** instructing the mobile drive unit **520** (e.g., FIG. **7**) to drive down the ramp **502** en route to another destination within the inventory system **10** (e.g., FIG. **1**). The mobile drive unit may recognize a fiducial **768** (e.g., FIG. **10**) visible through an opening **708** in the pallet **704**. The mobile drive unit may use the fiducial **768** for navigation. In some embodiments, an operator may provide a command to the mobile drive unit to move off of the pallet **504** before connecting the mobile drive unit to the management module **15** and/or may provide the appropriate initiation to bring the mobile drive unit into communication with the management module **15**. Alternatively, in some embodiments, a person can physically push the mobile drive unit **520** off of the pallet **504** via the ramp **502**, such as if an inoperable component of the mobile drive unit **520** renders providing a task assignment **18** to the mobile drive unit **520** impractical.

At **940**, the pallet can be disengaged from the base. For example, with reference to FIGS. **6-7**, the forklift **533** can lift the now-empty pallet **504** from the base **506** so that the protrusions **512** are no longer engaged with the openings **508**.

In some embodiments, the protrusions **512** may be retracted from the openings **508** to disengage the pallet **506** and base **504** without lifting the pallet **504** or necessarily removing the pallet from the base **506**.

At **945**, the pallet can be removed from the base. For example, with reference to FIG. **9**, the now-empty pallet **704** may be lifted from the base **706** until the posts **744** are clear of the guides **756** and/or until no part of the pallet **704** remains in contact with any part of the base **706**. The removed pallet may be moved to an area where empty pallets are being stored.

At **950**, the pallet can be stored. For example, posts **844** may be moved into a stored position, and the pallet **804** may be placed in a condensed stack **882** (e.g., FIG. **13**). In some embodiments, the posts **844** be kept in an upright supporting position when stored (e.g., FIG. **13** without mobile drive units **804**).

In embodiments, operations **910** through **950** may be repeated to introduce multiple mobile drive units **520** from multiple pallets **504** into an inventory system **510** using a single base **506**. In some embodiments, multiple bases **506** may be used in order to expedite an unloading process. Upon unloading a desired number of mobile drive units, at operation **955** the base can be removed. For example, the base **506** can be unbolted or otherwise detached from the floor. The ramp **502** may also be removed, if utilized. The removed base **506** and ramp **502** can be stored with the pallets **504** for subsequent use when palletizing, shipping, storing, testing and/or unpalatizing other mobile drive units.

FIG. **15** is a flowchart illustrating a process **1000** for “palletizing” or loading mobile drive units onto pallets according to a particular embodiment. In some embodiments, the mobile drive units can be palletized to prepare the mobile drive units for storage or shipment from one location to another. In some embodiments, the mobile drive units can be palletized in order to facilitate testing of the functionality of the mobile drive unit prior to implementation or shipping of the mobile drive unit.

At **1005**, a base can be installed. For example, the base **506** depicted in FIG. **6** can be installed. The installation process can be similar to that described above with respect to operation **905**.

At **1010**, an empty pallet can be obtained. For example, the empty pallet can be obtained in a similar manner to that described with regard to operation **910** described above. A pallet **804** may be obtained from a stack **882** of pallets **804** having posts **844** in a stored position (e.g., FIG. **13**). Posts **744** of the pallet **704** may be moved to an upright supporting position (e.g., to the position shown in dashed lines in FIG. **11**) to prepare the pallet to receive a mobile drive unit.

At **1015** and **1020**, the empty pallet can be respectively aligned with the base and engaged with the base. These operations may be performed in manners similar to those described with regard to operations **915** and **920** described above. Regardless, engaging the empty pallet **704** with the base **706** can provide a combined surface **766** navigable by a mobile drive unit (e.g., FIG. **10**).

At **1023**, an indication may be provided that the empty pallet is in place. For example, the operator of the forklift may provide the indication via a user interface **580** (e.g., FIG. **7**). The user interface **580** may include a touchscreen or other input device mounted to the forklift or otherwise accessible to the operator of the forklift or another individual involved in the process **1000**. The user interface **580** may communicate with the management module **15** or other parts of the inventory system **110**. In some embodiments, the pallet **504** or base **506** can include components that will automatically communicate to the management module **15** that the pallet **504** is in

place. For example the pallet may include an RFID tag and the base **506** may include an RFID reader or vice versa. Other alternatives include pressure-sensitive sensors to indicate that a pallet is in place in response to the weight of the pallet being detected by the sensor.

At **1025**, a mobile drive unit can be instructed to move onto the pallet. For example, in response to the indication that the pallet is in place, the management module **15** may provide a task assignment **18** to a mobile drive unit **20** to move to a fiducial **768** associated with the base **706** and/or pallet **704** (e.g., FIGS. **1& 10**). In some embodiments, a mobile drive unit **520** (e.g., FIG. **7**) may be instructed to move onto the pallet **504** by a technician providing instructions to the mobile drive unit through an interface other than the management module **15**. Alternatively, in some embodiments, a person can physically push the mobile drive unit **520** onto the pallet **504** via the ramp **502**, such as if an inoperable component of the mobile drive unit **520** renders providing a task assignment **18** to the mobile drive unit **520** impractical.

At **1030**, the pallet, now supporting the mobile drive unit, can be disengaged from the base. For example, the pallet **504** may be disengaged from the base **506** in any of the manners described above with respect to operation **940**. Disengaging the pallet **504** from the base **506** may allow features **532** of the drive unit to nest into the openings **508** of the pallet **504** that are no longer occupied by the protrusions **512** of the base **506**.

At **1035**, the pallet can be removed from the base. For example, the pallet **704** may be removed from the base **706** in any of the manners described above with respect to operation **945**. The pallet **704** may be moved to an area in which the pallet **704** will not be obstructing access to the base **706** by another pallet **704**.

At **1040**, restraints may be connected to the mobile drive unit and/or pallet. For example, the restraints **878** may be placed over the drive unit **820b** and connected in recesses **842** in the pallet **804b** (e.g., FIG. **12**). Connecting the restraints **878** may prevent the mobile drive unit **820b** from becoming jostled loose from the pallet **804b** during shipping or other operations.

At **1045**, the mobile drive unit can be powered down. For example, an operator—such as the forklift operator or another technician—can power down the mobile drive unit **520** while it is on the pallet **504** (e.g., FIG. **6**). In a particular embodiment, the mobile drive unit **520** may be powered down after being lifted from the base **506** so that an operator need not bend down to power down the mobile drive unit **520**. The operator may safely power down the mobile drive unit **520** in such an embodiment because the features **532** that would allow the mobile drive unit **520** to move are extended in the openings **508** of the pallet **504**, thus preventing the mobile drive unit **520** from moving from the pallet **504** and/or endangering the operator.

At **1050**, the pallet carrying the drive unit can be stored and/or shipped. For example, with reference to FIG. **12**, the pallet **804b** with a mobile drive unit **820b** may be stacked in a stack **882** on top of and/or underneath other pallets **804a**, **804c**, **804d** containing mobile drive units **820a**, **820c**, **820d**.

In embodiments, operations **1010** through **1050** may be repeated to palletize and/or load multiple drive units **520** on multiple pallets **504** using a single base **506**. In some embodiments multiple bases **506** may be used in order to expedite a loading process. Although a single base **506** may be used for a single pallet **504**, using a single base **506** for multiple pallets **504** can reduce a number of bases **506** to be fabricated or shipped in order to accomplish a particular loading, unloading, palletizing, or unpalatizing process. Upon loading or unloading a desired number of mobile drive units, at **1055**, the

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base or bases **506** can be removed. For example, the base may be removed in any of the ways described above with respect to operation **955**. Removing the base **506** may facilitate transporting the base **506** to another location where mobile drive units **520** are to be palletized, shipped, stored, tested and/or unpalletized.

Other variations are within the spirit of the present disclosure. Thus, while the disclosed techniques are susceptible to various modifications and alternative constructions, certain illustrated embodiments thereof are shown in the drawings and have been described above in detail. It should be understood, however, that there is no intention to limit the invention to the specific form or forms disclosed, but on the contrary, the intention is to cover all modifications, alternative constructions and equivalents falling within the spirit and scope of the invention, as defined in the appended claims.

The use of the terms “a” and “an” and “the” and similar referents in the context of describing the disclosed embodiments (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. The terms “comprising,” “having,” “including,” and “containing” are to be construed as open-ended terms (i.e., meaning “including, but not limited to,”) unless otherwise noted. The term “connected” is to be construed as partly or wholly contained within, attached to, or joined together, even if there is something intervening. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., “such as”) provided herein, is intended merely to better illuminate embodiments of the invention and does not pose a limitation on the scope of the invention unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the invention.

Preferred embodiments of this disclosure are described herein, including the best mode known to the inventors for carrying out the invention. Variations of those preferred embodiments may become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventors expect skilled artisans to employ such variations as appropriate and the inventors intend for the invention to be practiced otherwise than as specifically described herein. Accordingly, this invention includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the invention unless otherwise indicated herein or otherwise clearly contradicted by context.

All references, including publications, patent applications and patents, cited herein are hereby incorporated by reference to the same extent as if each reference were individually and specifically indicated to be incorporated by reference and were set forth in its entirety herein.

What is claimed is:

1. An inventory system, comprising:

- a mobile drive unit comprising a body having a bottom surface and a plurality of features extending below the bottom surface;
- a base comprising a plurality of protrusions; and

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a pallet comprising a support surface and a plurality of openings extending through the support surface, the plurality of openings arranged such that, (1) in an engaged configuration, the plurality of protrusions on the base project into the plurality of openings in the pallet such that the plurality of protrusions and the support surface together form a combined surface navigable by the mobile drive unit, and (2) in a separate configuration, when the base is disengaged from the pallet so that the protrusions are no longer within the openings and the mobile drive unit is positioned on the pallet, the plurality of features of the mobile drive unit are positioned within the plurality of openings.

2. The inventory system of claim 1, wherein the plurality of features comprises at least one of a wheel, a caster, an axle, or a yoke.

3. The inventory system of claim 1, wherein the pallet further comprises one or more restraints arranged to secure the mobile drive unit to the pallet in the separate configuration.

4. The inventory system of claim 1, further comprising a ramp configured to provide a path from a floor upon which the base is installed to the combined surface.

5. The inventory system of claim 1, further comprising: an obstruction configured to block a path of the mobile drive unit to the base when the base is not engaged with the pallet.

6. The inventory system of claim 1, wherein at least one of the plurality of protrusions of the base includes a fiducial marker readable by the mobile drive unit.

7. The inventory system of claim 1, wherein the pallet comprises a first pallet having a set of posts arranged for supporting a second pallet relative to the first pallet when the first pallet is in the separate configuration.

8. The inventory system of claim 7, wherein the set of posts are foldable such that the pallet occupies a smaller volume in an empty configuration in which the pallet is not supporting a mobile drive unit than in a loaded configuration in which the pallet is supporting a mobile drive unit.

9. The inventory system of claim 1, further comprising a management module configured to: receive an indication that the pallet is in the engaged configuration; and instruct the mobile drive unit to drive onto the combined surface of the pallet and the base.

10. The inventory system of claim 1, wherein the pallet further comprises a metal frame, and wherein the support surface of the pallet comprises a wooden layer coupled with the metal frame.

11. A method comprising: engaging a pallet with a base so that a protrusion of the base is positioned within a corresponding opening of the pallet; positioning a mobile drive unit on the pallet so that a feature of the mobile drive unit is positioned over the protrusion that is positioned in the corresponding opening of the pallet; and disengaging from the corresponding opening the protrusion over which said feature of the mobile drive unit is positioned so as to position said feature within the opening.

12. The method of claim 11, further comprising: providing an indication that the pallet is engaged with the base, wherein the positioning the mobile drive unit on the pallet includes instructing the mobile drive unit to drive onto the pallet in response to the indication that the pallet is engaged with the base.

13. The method of claim 11, wherein the disengaging comprises lifting the pallet with respect to the base.

14. The method of claim 11, further comprising:

stacking the disengaged pallet on a second pallet, wherein the second pallet is supporting a second mobile drive unit such that a feature of the second mobile drive unit is positioned in a corresponding opening of the second pallet.

15. The method of claim 11, further comprising:

performing testing associated with a characteristic of the feature positioned within the opening.

16. A method comprising:

supporting a mobile drive unit on a pallet such that a feature of the mobile drive unit is positioned within a corresponding opening of the pallet; and

engaging the pallet with a base so as to position a protrusion of the base within said opening of the pallet and move said feature out of the opening.

17. The method of claim 16, further comprising:

communicating information about the mobile drive unit to a management module.

18. The method of claim 16, further comprising:

releasing restraints securing the mobile drive unit to the pallet.

19. The method of claim 16, further comprising:

instructing the mobile drive unit to drive off the pallet.

20. The method of claim 16, further comprising:

installing the base to a floor in an inventory system; and removing the base from the floor.

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